Magnet Fabrication

With examples drawn from
The Main injector Project

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Magnet Fabrication

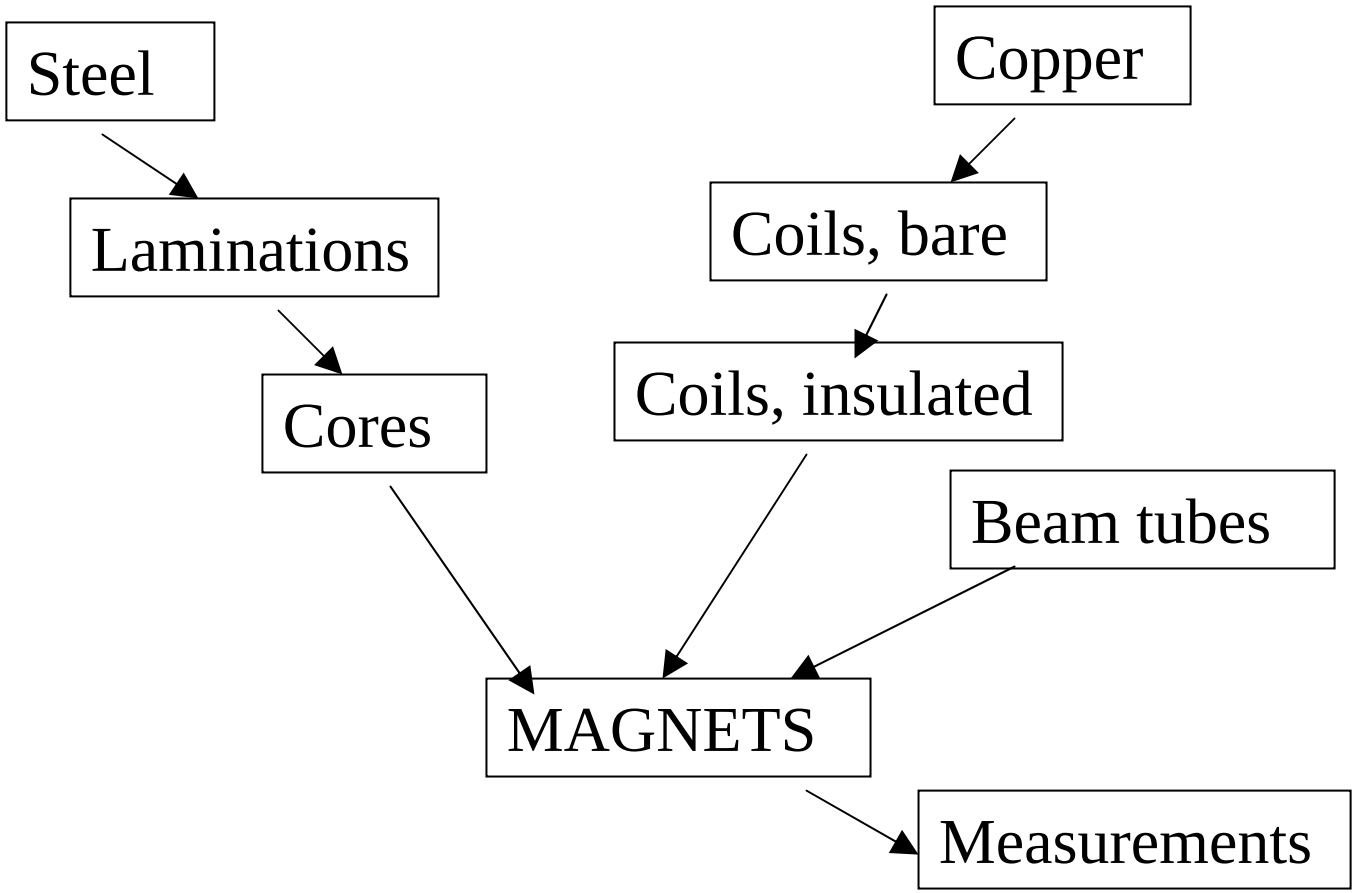
- Conventional magnet fabrication
- Main Injector Project magnet production
- Superconducting magnet fabrication

- Tour

Broad questions

- Contracted or in-house
- Build-to-print or build-to-spec
- General contractor
- Quality assurance

Conventional Magnet Fabrication



Steel specifications

- Chemistry & heat treatment or performance
- Permeability, coercivity
- Thickness, crown
- Coating
- Width of master coil, slitting
- Shipping and handling
- Consistency or shuffling for homogeneity

Laminations

- Dimensional tolerances
- Monitoring
- Adjustments
- Burr
- Handling

Stacked cores

- Lamination recipes
- Mechanical tolerances
- Packing factor
- Handling
- End packs, plates

Copper

- Chemistry
- Hardness
- Dimensional tolerances
- Center hole

Bare coils

- Dimensions
- Wind or form
- Brazing process
- Testing

Insulated coils

- Dimensions
- Insulation integrity
- Epoxy - resin, hardener, accelerator
- Other materials
- Tooling
- Process
- Testing

Beam Tubes

- Watch permeability, especially of seam
- Seam location
- Formed, drawn, deformed
- Swabbed, ultrasound, vacuum bake-out
- Bellows, flanges, other accoutrements

Final Assembly

- Coils into core
- Weld up cores
- Water manifolding
- Power bussing
- Beam tube
- Detailing
- Alignment

Magnet Measurements

- 100% or sample

- In-process tuning
- Provide a final quality assurance check
- Allow placement of magnets to improve accelerator performance
- Document properties for later understanding

Main Injector Production

How we did it

- Design
- Prototyping
- Procurement
- Fabrication
- Measurement

⚐Quality Assurance

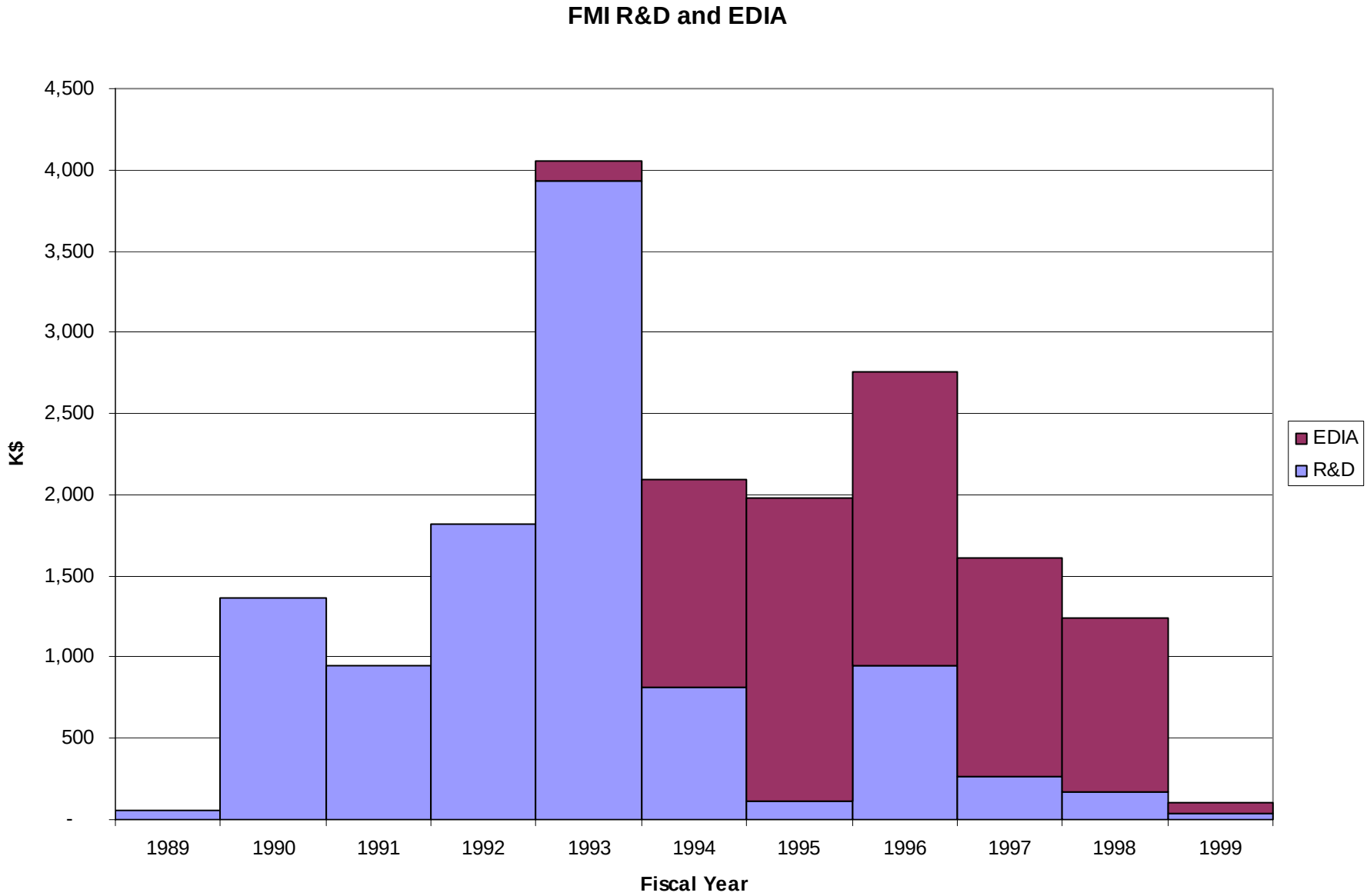
Design

- Interplay among participants

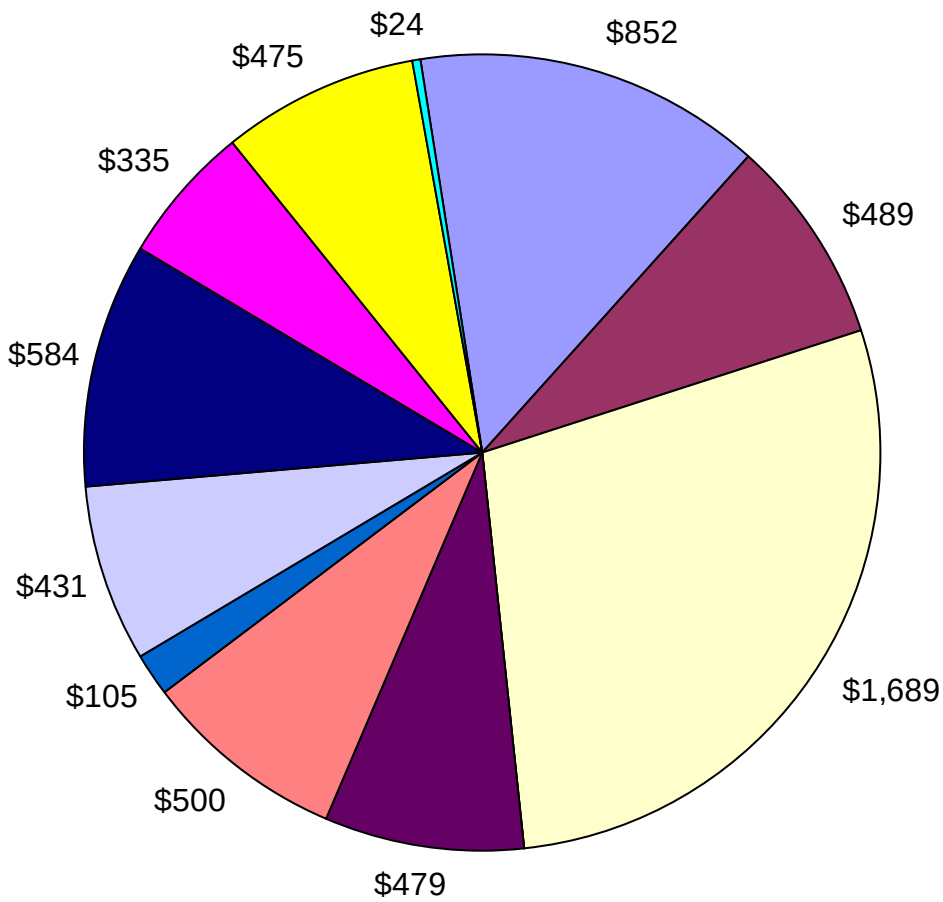
- Machine physicist(s)
- Magnet physicist(s)
- Magnet engineer(s)
- Magnet designer/drafter(s)
- Procurement specialist(s)
- Measurement physicist(s)

Dipole Parameters

	IDA/IDB	IDC/IDD
Length (meters)	6.096	4.064
Strength (Tesla)	1.72	1.72
Gap (mm)	50.8	50.8
Turns/pole	4	4
Conductor Dimensions (in x in)	1.00 x 4.00	1.00 x 4.00
Conductor Hole Diameter (in)	0.500	0.500
Current at 150 GeV (A)	9244	9244
Current at 120 GeV (A)	7035	7035
RMS Current (A)	4987	4987
Coil Resistance (mW)	0.8	0.6
Coil Inductance (mH)	2.0	1.3
Peak Power (kW)	69.8	53.0
RMS Power (kW)	19.8	15.0
Number Used	216	128
Weight (kG)	17000	12000
Sagitta (mm)	16	7


FMI R&D and EDIA
4,500
4,000
3,500
3,000
2,500
2,000
1,500
1,000
500
-
K$
1989
1990
1991
1992
1993
1994
1995
1996
1997
1998
1999
Fiscal Year
EDIA
R&D

Main Injector magnet R&D costs breakdown (K$ 1989-1999)



Prototyping

- 1 magnet in 1990-91
- 1 magnet in 1991-93

  13 different ends

- 10 magnets in 1993

  Qualifying vendors

Procurement

- Source evaluation board
  - Bare coils
  - Insulated coils (three R&D vendors)
  - Half cores (two R&D vendors)
- Bids
  - Steel (sample production)
  - Laminations
  - Beamtubes (samples)

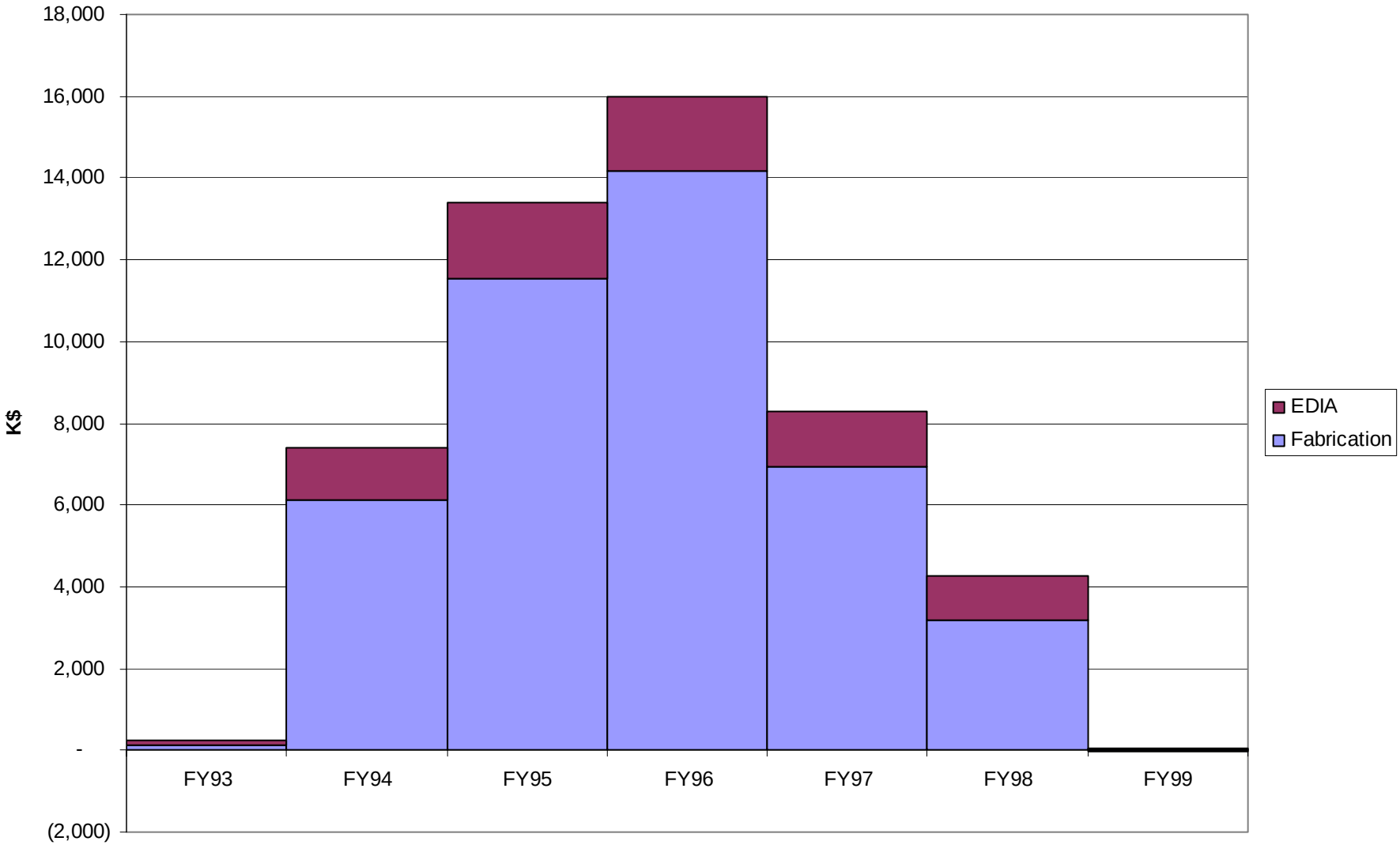
Fabrication

- Conventional Magnet Facility
  - Tooling Group
    - Technicians
  - Production Group
    - Lead technicians
    - Technicians, Fermilab
    - Technicians, contract
  - Process Engineering Group
    - Traveler management
    - Technicians

Fabrication (continued)

- Material Control Department
  - Acquisition Group
  - Inspection Group
  - Magnet and Component Storage Group
- Engineering
  - Engineers
  - Designer/drafters

Main Injector Magnet Cost Profile



Magnet measurements

- Rotating tangential coil (100%)
  - Excitation on center ($\int B_y(x=0)dz$)
  - Harmonics on center
- FLATCOIL (100%)
  - Excitation on center ($\int B_y(x=0)dz$)
  - $\int B_y(x)dz$
- Point scan (25%)
  - NMR
  - Hall probe

Quality Assurance

- Design reviews
- User approval of configuration
- Production readiness reviews
- Incoming inspection of components
- Travelers
- Discrepancy reports
- On-line analysis of magnetic measurements

Alignment

- Conventional magnet alignment depends on steel
- Witness notches on outside of laminations
- Transfer to fiducials for tooling balls
- Fiducial at longitudinal center

Superconducting Magnets

- Coils
- Collars
- Iron Yoke
- Cryostat
- Testing

Coils

- Filaments ➚ strands ➚ cable
- Wind to precise location for good field
- Cannot move or magnet will quench
- Ends especially difficult

- Electrical connections

Collar laminations

- Constrain coil against movement
- Stainless steel or aluminum
- Pre-stress to accommodate differential thermal contraction
- Various ways of securing halves together

Iron yoke

- Laminations
- Provides flux return
- Further mechanical support
- Cold iron - warm iron choice

Cryostat

- Helium vessel
- Thermal radiation shield(s)
- Super insulation
- Vacuum vessel

- Internal supports
- Plumbing

Testing

- Quench testing
- Magnetic field quality
  - Warm, cold
- Alignment
  - Warm, cold